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HOME INSULATION, AN EFFECTIVE CONSERVATION AND NATIONAL-DEFENSE MEASURE

BY

PAUL M. TYLER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

HOME INSULATION, AN EFFECTIVE CONSERVATION AND NATIONAL-DEFENSE MEASURE [1]

By Paul M. Tyler [2]

Low-cost housing, like automobiles, should be appraised in the light not merely of first cost but of upkeep as well. Even more important than the number of miles the family car will go on a gallon of gasoline is the number of days the family home can be kept comfortable on a ton of fuel. A furnace tender who tossed every third shovelful of coal into the ashcan would lose his job promptly, but the effect is the same when homes continue year after year to pour out precious heat through uninsulated roofs and walls.

Greater economy in household heating means even more to the national economy than to the individual, especially now that we are preparing for defense. Our fuel resources, although large, should be conserved. If less fuel is used for civilian needs, augmented requirements for defense can be met without unduly increasing the number of men needed at the coal mines and oil wells or adding new producing units that might complicate ultimate readjustment to peacetime conditions when the emergency is past and over-expansion of many industries brings new problems. If unnecessary demands for transportation facilities are reduced, public carriers will be able to haul more munitions, and manpower needed for national defense will be released; and by protecting workers from health hazards in their homes additional man-hours of productive effort will be gained. Moreover, reducing the running expenses of houses by proper heat insulation helps home owners to maintain payments on property, and by minimizing foreclosures helps to stabilize the financial structure of the country. In short, here is a situation where the interests of the individual and the Nation are identical and the greatest good for the greatest number is obtained without sacrifice to anyone.

POSSIBLE SAVINGS

Ours is a lavish land. In contrast with the poverty general in other parts of the world, the life in any large American city seems wasteful in the extreme - the blaze of lights, the profligate consumption of gasoline in driving half-empty cars, the abundance of food, the extravagant clothing, and the overheated homes and offices. Much of this waste, however, is merely on the surface. The real enemy of abundant living is not so much visible as invisible waste. Because our homes are better-heated than foreign homes it does not mean that Americans are extravagant. In fact, a single central-heating unit may keep a whole house warm with less coal, or its equivalent in oil or gas, than our grandfathers burned in scattered fires in open grates that left chilly corners in every room.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7166."

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Fuel saving naturally begins at the source, and to produce heat efficiently for a given dwelling means selecting the proper fuel and burning it in a furnace designed to release as much as possible of the full heating value of the fuel where it will do the most good. This process is complicated and involves not only proper burning of fuel but also capture of the heat in a suitable transmitting medium - steam, water, or air. Efficient production of heat, therefore, is still a fruitful field for research in fuel saving. Studies of the efficient use of heat cover another vast technologic field and have proved invaluable to the commercial success of many process industries. True heat economy in the home, however, has never commanded the attention that it deserves.

The United States today contains some 37,000,000 dwelling units, and during the next few years fully a half a million more should be added annually, in addition to replacements. Defense housing alone is scheduled to provide 160,000 to 200,000 units, mostly frame structures costing an average of $3,500 each.

Supplies of fuel for domestic purposes, chiefly heating, are drawn from various sources. In 1939, for example, sales of fuel for domestic heating or for heating offices, apartments, hotels, schools, hospitals, and other buildings in which people must be warm in the United States, as estimated by the Bureau of Mines, included approximately 35,000,000 tons of anthracite, 55,000,000 to 75,000,000 tons of bituminous and other classes of coal, 9,000,000 tons of coke, 175,000,000 barrels of oil, and 760 billion cubic feet of gas. The total value of these fuels as reported by producers was more than $670,000,000. Including transportation charges and retailers' expenses and profits, the American people pay over $1,500,000,000 a year to keep themselves warm in their homes. Moreover, this figure does not cover the large quantities of wood used in fireplaces and stoves, much of which is cut and chopped by boys on the farm and thus escapes statistical analysis in dollar values. On the basis of the foregoing quantities, the average family uses nearly 5 tons of coal or equivalent fuel a year, and this estimate is low.

Average savings in coal-using efficiency in industry range from 20 percent in steel making to 56 percent in electric public-utility plants since 1918. Similar savings can be made in domestic heating. It has been estimated conservatively that fuel to heat the average American home in accordance with modern standards of comfort would cost about $75 a year without insulation and only about $40 a year with insulation. On the basis of an average saving of even $25 a year with insulation, 200,000 defense houses would save the Nation well over $5,000,000 a year if insulated. This saving is equivalent to 12,000 carloads of coal or 8,400 tank cars of oil. Additional savings might result from insulating cantonment buildings and other structures required to help make this country the "arsenal for democracy."

Most of the 500,000 new houses to be added annually will be financed by Government-insured loans. On the basis of $25 a unit as the possible saving due to insulation, the potential wastage, if the houses were not insulated, would be $12,500,000 in 1941, $25,000,000 in 1942, $37,500,00 in 1943, and so on until by the end of the tenth year it would amount to $125,000,000 annually. As the capital cost of insulation now can be repaid by the savings on fuel each year, no good reason is apparent for tolerating such waste in new construction. If similar savings could be applied to the 37,000,000 existing dwelling units in the United States, potential savings would be approximately $1,000,000,000 a year.

HOW INSULATION WORKS

James Watt insulated his primitive steam engine and its boiler with strips of wood, a proof that even then industry had begun to appreciate the economy of conserving heat energy. Mineral wool was used as steam-plant insulation as early as 1840. Whenever heat or refrigeration is used in industry, insulation guards against waste. In many modern industrial processes based upon reactions that take place only within a narrow temperature range, insulation not only is economical but necessary, because close temperature control is almost impossible without insulation.

Years ago, the National Bureau of Standards (T. I. B. M. 15, May 18, 1936) showed that frame construction, with wood shingles over building paper and 3/4-inch wood sheathing outside and 3/4-inch plaster and metal lath (or 1/2-inch plasterboard or wallboard alone) inside, had an insulating value[3] of 4.6, when the 3-5/8-inch air space was unfilled. When this space was filled with mineral wool the value rose to 16.0. Corresponding figures for a 4-inch brick-veneer wall over the same paper and sheathing and the same interior wall finish were 3.7 when the air space was unfilled and 15.1 when it was filled (T. I. B. M. 14)

Another interesting Bureau of Standards tabulation (T. I. B. M. 3, March 4, 1936) shows estimated fuel savings up to 40 percent due to the application of simple heat-loss preventives to walls and roof of an unprotected house, and with suitable weatherstripping and storm sash applied to doors and windows the total savings were boosted to 60 percent.

To the ordinary home owner insulation is simply a more or less effective barrier to retain heat in winter and keep it out in summer.

Heat is transferred in three ways - by conduction, convection, and radiation. With reference to insulation, conduction is the most important, and as heat is dissipated first through conduction a well-insulated surface automatically reduces convection and radiation losses to a minimum.

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[3] The unit in these tests was the number of hours required for passage of 1 B. t. u. of heat through 1 sq. ft. of wall area per 1° F. temperature difference between air on one side to air on other side.

Conduction, or the flow of heat through a solid, may be noted along a silver spoon when it is used to stir coffee. Convection is a more complicated phenomenon but is often manifested by "drafts" or movement of air, as well as by air leakage around window and door frames. Radiation is the process that carries the sun's heat to the earth and is familiar to anyone who has sat by an open fire; it also takes place between the objects in a room and the outside walls.

Although air is a poor conductor of heat, open air spaces in the hollow walls of a building do not afford much insulation, largely because of radiation from one wall to the other. Some heat also is lost by convection (the term "dead-air space" is a misnomer), but not so much as many suppose.

In any enclosed structure where human beings should be comfortable in winter - home, factory, office building, or school - the principal function of the heating system is to prevent body heat from being dissipated too rapidly for health. If walls, ceilings, or floors become too cold discomfort results, and even with the finest heating plant in the world exposed surfaces are likely to become too cold unless they are heavily insulated. The same insulation helps to keep surfaces cool in summer.

Heat is measured in British thermal units; 1 B. t. u. is the heat required to raise 1 pound of water 1° F. under specified conditions (from 39° to 40° F. at sea level). Heat losses are measured in B. t. u. per square foot per hour per ° F. temperature difference; in other words, in terms of the quantity of heat that will pass through a section of given material, 1 square foot in area and 1 inch thick, in an hour, divided by the difference between the outside and inside temperatures. This quantity is sometimes called the k-factor, and as it is the measure of heat loss the smaller this constant is for a given material the better the insulating properties of the material. The thermal conductivity or k-factor of most light, fibrous materials sold primarily as insulators ranges from 0.25 to 0.35 B. t. u. per hour.

Heating requirements are measured by engineers in degree-days. The heating season in the United States is roughly October 1 to May 1, but it varies greatly in different parts of the country. Degree-days, however, are published in heating handbooks and in United States Weather Bureau reports for nearly every city in the United States and Canada. They are based upon mean-temperature data. One degree below 65° F. for a 24-hour period equals 1 degree-day. The assumption is that no artificial heat is required when the mean daily outside temperature is 65° F.

SERVICE TESTS

Laboratory tests can be conducted under ideal circumstances, but many field tests have been made to prove the resistance of walls and roofs to passage of heat in houses of different types, subject to variable wind velocity and sharp changes in temperature and humidity. One of the first series of practical field tests on house insulation ever conducted by the

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Federal Government is reported in an official bulletin of the Tennessee Valley Authority, entitled "Studies in the Heating of Small Houses," published in June 1939. These tests revealed that complete wall, floor, and roof insulation may cut the fuel bill of a typical house in a relatively moderate climate as much as 44.75 percent. They further indicate that the saving might be increased to 50 percent. The tests were conducted in two adjoining basementless houses in the Hiawasee Dam community of North Carolina with occupants actually living in the house.

In these small houses the extra cost of insulation was only $113, about one-half of which might be saved under normal circumstances in a newly built house because of the smaller heating plant that would be required. In a hypothetical northern locality with what is technically known as a 6,000-degree-day heating season, yearly dividends would be $45.50 heating with electricity at 1 cent a kilowatt-hour, $13.20 using oil at 8 1/2 cents a gallon, and $11.93 for coal at $12 a ton.

Even in the mild climate of Hiawasee, N. C., the savings in dollars and cents were worthwhile. The tests proved that insulation, in this case mineral wood, does not cost the house owner a cent. It begins to pay for itself the day it is installed and continues to do so as long as the house is occupied. John B. Rodee, of the Pierce Laboratory of Hygience, Hartford, Conn., addressing architects and builders (Architectural Forum, March 1940), points out that if someone broke a window the owner of the house would replace it as quickly as possible, as the heat that would escape through the broken pane would soon cost more than replacing the glass. Although the heat that escapes through an uninsulated wall is not so obvious, the principle is the same. Rodee then shows that the cost of insulation, divided over the period of an ordinary loan, is much less than the saving in fuel. For example, it will cost $75 to heat a small, uninsulated house in Milwaukee, Wis., but heat plus deferred payments on insulation with full-thick mineral wool will cost only $42 annually for the same house, when paid for like the rest of the house over a 20-year period, including interest. This means a saving of $33 a year until the loan is paid off, after which the saving goes up to $42.

Vouched for by vermiculite producers is a test conducted in twin houses on Pennington Drive, Detroit. One house, uninsulated, was sheltered on both sides by other houses. The other house, a few doors away, was exposed on three sides but was insulated. Throughout the winter of 1935 and 1936 an attempt was made to keep both houses at a constant temperature of 74° F. During October 1935 the insulated home burned only 98 gallons of oil compared with 168 gallons burned in the uninsulated home, and for the entire heating season the average monthly saving on fuel bills was 38 percent. As a further "dividend," temperatures in the insulated home never fluctuated more than 2° F., whereas in the other home they varied as much as 18° F. in a 24-hour period.

"EXTRA DIVIDENDS" TO HOME OWNERS

Modern transportation enables the wealthy and many of the poor to migrate with the birds south in winter and north in summer, but for middle-class folks who have regular jobs and must "stay put", insulation is a thrifty means of maintaining homes at comfortable temperatures both summer and winter. Combined with automatic heating in cold weather, insulation does away with early-morning shivers, eliminates chilly drafts along the floors, and cuts down on house cleaning due to dirt and dust from overworked furnaces. In summer it may make the difference in an upstairs bedroom between temperatures insufferable for sleeping and reasonable comfort. Uninsulated houses frequently are hotter than outdoors, as they trap the heat on long sunny days.

Extra sleeping hours may be gained through another means - sound absorption. Street noises, unfortunately, come in principally through the windows but other disturbing sounds transmitted through walls are deadened by the materials used to bar heat.

Each year, according to the National Fire Protection Association, fires occur in nearly 400,000 places where people live and cause the death of 7,500 persons, mostly women and children. Incombustible heat-insulating barriers in roofs and walls make even frame buildings slow burning. In earlier years, when insulation cost more, salesmen stressed its fire-resistance more than its comfort and fuel-saving properties. The George Washington shrine at Mount Vernon was insulated on the recommendation of the National Bureau of Standards because mineral wool installed between rafters and in the walls around dormer windows would inhibit the spread of fire. Recent tests at the National Bureau of Standards show that a wood-lath partition filled with mineral wool will stop the passage of fire for 1 hour. After this long period of exposure the studs were still able to carry their load.

Still another "extra dividend," seldom stressed but well-recognized by mortgage lenders, is the fact that insulation in side walls and ceilings reduces the number of times that the interior of a house must be redecorated during the lifetime of a loan. With wallpaper and paint in better condition the house is not only a better place in which to live but a better mortgage risk; it is easier to rent or sell, and as redecorating costs as well as fuel costs come out of the borrower's income the chances of delinquent payments are reduced. Dust patterns and alternate light and dark strips along lath and beam locations are less likely to occur in well-insulated homes. In the first place there is less movement of air to carry particles of dust along unevenly heated surfaces and in the second place there is less condensed moisture on the surfaces to catch the dust. Moreover, as cold walls are likely to be damp, condensed moisture alone may cause discoloration.

HOW TO INSULATE

Insulation is no better than the man who installs it. Any competent architect or builder can furnish figures as to the type and thickness of insulation that will save the most fuel-dollars in a given building. Generally, mineral materials are preferable because of their resistance to fire, electrical short circuits, moisture, termites, vermin, and decay. Full-thick insulation ordinarily is most economical, and most manufacturers recommend 3-5/8 inches, which is the thickness of the hollow space in most walls. No insulation is expensive in first cost, but some are expensive later. Mineral wool or vermiculite furnished by reliable manufacturers is of standard quality and usually is as cheap and efficient as any material, but in places aluminum foil, metallic paint, or various other good insulating mediums or combinations of these with mineral wool or vermiculite may be indicated. It should be remembered also that heat may be lost through single-glass panes in windows, thin and badly fitted doors, and general leakage of air.

For typical suburban homes it has been estimated that 60 percent of the heat lost in winter filters through the side walls and 40 percent through the roof. About one-third of the heat gained in summer enters through the side walls and two-thirds through the roof. Obviously both should be insulated for maximum year-round comfort and economy.

Everyone is familiar with condensation of moisture on window panes in cold weather. So-called "steamy" windows signify overhumidification (too much moisture) in the air. Often this condition can be controlled or eliminated by opening the windows or, better, by the use of ventilating fans to draw off water vapor from laundry, bathrooms, or kitchen. Much the same problems arise in respect to insulation, and instances have been recorded where interior sweating of walls and even damage from freezing of water condensed in walls have resulted from improperly placed insulation. In field examinations, however, United States Forest Products Laboratory research workers have "not found serious conditions in full-thick insulation blown into older houses where reasonable humidities were maintained." Overhumidification affects many building materials, hence the National Paint, Varnish & Lacquer Association has recommended that the inside relative humidity should never exceed 40 percent and that when the outside temperature is below zero it should not exceed 20 percent.

Although hundreds of thousands of insulation jobs have been successful without vapor barriers, modern types of mineral wool for new construction are sold with vapor barrier attached. The batts or strip have a moistureproof paper on one side which is applied, inside the studs or under the rafters, nearest the warm side, thus preventing moisture carried by the warm air inside from reaching the hollow spaces or the outer sheathing where it might condense. Attic ventilation also helps to prevent condensation and should always be provided above insulation; it has the further function of eliminating excessive summer heat. For natural ventilation louvers having a minimum free opening of 12 1/2 square inches for every 100 feet of ceiling area should be placed at opposite ends of the building.

Another cause of complaint is slumping. Occasionally walls that presumably were filled with mineral wool or vermiculite have been found to contain open spaces, and horizontal layers originally supposed to be 4 inches thick have slumped to say 3 inches after standing a year or two. Ordinarily these conditions come about only when the original installation was made by inexperienced or irresponsible contractors.

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The natural time to install insulation is when the house is first build, as it costs less then; however, insulation can be added to existing homes at any time with relatively little expense compared with the resulting saving in fuel costs and gain in comfort. Fully 800,000 old homes had been insulated by the end of 1940, and 20 to 30 times this number could be so modernized with advantage to the owners and to the Nation.

MISCELLANEOUS PRODUCTS

The most widely used material for effectively insulating houses is mineral wool, which is manufactured in 75 plants in various Stated. The raw material used in its manufacture determines whether it is rock wool, slag wool, or glass wool. It may be sold packed loose in 4-cubic foot bags, just as it comes from the receiving chamber. This form can be placed by hand into open spaces or spread between the ceiling joists. Nodulated or granulated wool has been freed from shot and rolled into small pellets so that it can be blown into place through an air hose; it is used chiefly for insulating houses already built. Increasing quantities of wool are fabricated into soft, flexible quilts, confined between layers of vapor-proofed paper. "Batts" are rectangular shapes made from loose wool mixed with suitable binders, compressed, and cut to the thickness and size demanded by consumers. Batts may have one or two paper covers or none at all. They are used for insulating new houses, being inserted in walls, floors, or roofs between studs, joists, or rafters. Roll wool is wool matted like cotton batting and rolled with paper. Blankets, used largely for insulation in industrial furnaces, are made of loose wool treated with various binders and are of various rectangular shapes and thicknesses, sewed between wire, metal lath, or other confining media. Loose wool with suitable binders also is compressed into blocks for use in refrigerator, stove, and furnace insulation and into various shapes for pipe and boiler coverings. Loose wool mixed with bentonite or plastic fire clay and asbestos fiber is sold as an insulating cement for filling joints between insulating blocks, as plastic insulation for irregularly shaped objects, and for general heat-conservation use.

Another important mineral insulating material commonly used is vermiculite, which is mined mostly in Montana and processed in plants situated at various strategic points in the United States, Canada, and even Europe. It is a micalike mineral which expands greatly when heated, forming feather-light, resilient pellets which, when screened or sized to remove particles that are too large or too small, are used as loose fill. It can be poured from the bag. Insulating cements made from expanded vermiculite screenings and bentonite or other binder are manufactured by several firms, and at least one manufacturer has produced a compressed vermiculite wallboard. Plaster and concrete, in which vermiculite takes the place of sand or other aggregate, are being used in rapidly increasing quantities; in addition to their heat-insulating value, they have acoustic properties and are light in weight. Vermiculite precast concrete slabs for roof, floor, or wall construction weigh as little as 25 pounds per cubic foot and are easy to install. If necessary they can be sawed, cut with a knife, drilled, or nailed in much the same way as wood lumber. Vermiculite concrete (1 part portland cement, 8 parts "Zonolite") has almost half the heat-insulating value of loose vermiculite.

Stiff, fibrous insulating boards having considerable structural strength usually are not as good insulators as lighter and looser materials, and dense, highly compressed wallboards made of wood or other organic fiber are even poorer insulators than less-compressed boards of the same general composition. Heavy wallboards containing some form of gypsum, although excellent building materials, are relatively poor insulators.4/

Aluminum foil is used to increase the value of air spaces by reducing heat transfer by radiation. Clean metallic surfaces usually are good reflectors and poor emitters of radiant heat, and as much of the transfer of heat across open spaces in buildings takes place by radiation, the use of aluminum on one or both sides of the space may reduce heat losses substantially. Aluminum foil also is applied in crumpled form to be self-spacing.

Diatomite, pumice, and other porous rocks or earths have been used for wall insulation, and diatomite, asbestos, and magnesia (chiefly a mixture of 85 percent technical carbonate and 15 percent asbestos or other fiber) are used extensively for boiler and pipe coverings. Balsam wool, animal hair, cork, and sundry vegetable fibers also are listed among materials used to impede the transfer of heat.

Density is a factor in all building materials, not only because freight rates boost their cost delivered on the job but also because lighter loads do not require costly framework. Ordinarily, the lower the density, the better the insulating value.

Available data for specified materials are summarized in the accompanying table.

4/ National Bureau of Standards, Technical Information on Building Materials: No. 16, May 22, 1936.

Thermal conductivity of various materials [1]

Material tested	Density, lb. per cu. ft	Conductivity
Air space between walls (3 1/2-in.)	0.081	0.86 to 1.10
Cotton, compressed................	6.3	.21 to .29
Pure wool	6.24	.26 to .32
Silk	6.24	.28 to .34
Hair felt	13.0	.26
Flax fiber	13.0	.31 to .33
Cork, ground	8.1	.27 to .31
Sugarcane fibers	13.5	.34
Pine wood	34.3	.8 to 1.0
Wood-pulp board, plaster base	16.2	.3 to .4
Mineral wool	21.2	.27 to .30
Asbestos sheet	48.3	.29
Magnesia (85 percent magnesia, 15 percent asbestos)	19.3	.47 to .51
Expanded vermiculite	6.0	.26
Diatomite powder	10.6	.3 to .5
Diatomite blocks	28.1	.58
Pumice gravel	18.8	.64
Tile (clay and plaster)	12.7	.60
Glass, plate	15.5	3.5 to 5.5
Bricks, dry	125.0	3.0 to 6.0
Brickwork (mortar bond)	132.0	4.0 to 5.0
Gypsum plaster	46.2	2.0 to 5.0
Concrete, 1-2-4	150.0	5.0 to 6.0
Slate shingles	162 to 205	10.0 to 10.4
Building stone	165.0	12.5
Steel, 1 percent carbon	489.0	314.0 to 328.0
Copper pure	558.0	2,580.0 to 2,670.0
Silver, (greatest conductivity) ...	655.0	2,860.0 to 2,920.0

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[1] Authorities: National Bureau of Standards, Federal Housing Administration, and university and research laboratories.

[2] Conductivity = British thermal units transmitted per hour per square foot of material 1 inch thick, per ° F. difference in temperature of the two faces.

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